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(54) IMPROVEMENTS IN OR RELATED TO FLUIDISED BEDS AND THEIR OPERATION

(71) We, HUMPHREYS & GLASGOW LIMITED, a British Company, of 22 Carlisle Place, London, SW1P 1JA, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to fluidised beds, particulary those using a gas/solid system, and to their operation.

Fluidised beds are now-a-days extensively used in the chemical and process industries in view of the extremely intimate gas/solid contact obtainable therewith. High rates of heat and mass transfer can be obtained between the solid material and the gas passing through the bed which make the gas/solid fluidised bed system a very good chemical reaction environment. The reactants can be wholly gaseous with the solid material of the bed functioning as a catalyst, or the solid material can itself be one of the reactants. An example of the former case is the catalytic cracking of hydrocarbon feed stock, whilst an example of the latter case is the gasification of carbonaceous fuels. The gas/solid fluidised bed is also useful for performing purely physical processes like gas drying or the absorption of impurities from gas streams.

In the vast majority of operations in which the fluidised bed takes part, heat is required to be transferred into or out of the bed. When large scale processes are considered, the difficulties of transferring enough heat efficiently are considerable. The gasification of carbonaceous fuel may be taken as an example. Here it is common practice to perform the gas-producing reaction in a fluidised bed (hereinafter referred to as the Reaction Bed) using hot particles of carbonaceous material. The reaction is, however, in general endothermic and considerable quantities of heat must be supplied to the bed in order to maintain the reaction. This heat can conveniently be supplied by combustion of a portion of the carbonaceous fuel, and various ways have been devised for transferring this heat to the reaction bed. In one method hot carbonaceous material from the combustion process is conveyed to the reaction bed using well known solids handling technology. However, calculations show that the quantity of hot solid material required to be transferred becomes prohibitively large when big modern gasification plants are considered. Thus, for example, the endothermic heat requirements of such a plant may be about 10 million kilogramme calories per hour. Working on a 150 deg. C temperature difference between the combustion process and the gasification process, the amount of hot carbonaceous material required to be transferred would be approximately 200 tonnes per hour.

A major disadvantage of such a method is the provision of large ducts for the transferring solid materials. Gases from the combustion and the gasification processes can pass through these ducts, unless very expensive precautions are taken, which leads to undesirable contamination of the gases. Also the nature of the two processes involved tend to put different demands on the carbonaceous material: the combustion process can tolerate a relatively high ash content in the carbonaceous material whereas the gasification process prefers a low ash content.

The present invention seeks to overcome the difficulties arising from the need to transfer heat into or out of a fluidised bed by providing means for effecting the efficient transfer to heat directly into or out of the bed.

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In accordance with the present invention there is provided in combination, a gas/solid fluidised bed, a heat sink or heat source, and, as means via which heat is transferred between the heat source or heat sink and the bed, at least one heat pipe partially immersed in the bed.

The invention also provides a method of operating a gas/solid fluidised bed which comprises passing gas through a solid-containing fluidised bed and controlling the temperature of the bed at least in part by means of at least one heat pipe, partially immersed therein, combined with a heat source or heat sink.

In a preferred embodiment, the heat source or heat sink comprises a second gas/solid fluidised bed in which the heat pipe or pipes is or are partially immersed. It is convenient to dispose the containing vessel for the first fluidised bed within the vessel containing the second fluidised bed. In this way the length of the heat pipe or pipes can be reduced and thermal losses decreased. Means can be provided for substantially preventing the intermixing of the gases flowing to and/or from the first and second fluidised beds. In some systems, means can also be provided for transferring solid material between the beds.

The combination of the present invention has particular utility where the first fluidised bed is used to perform an endothermic reaction, whilst the second performs an exothermic reaction. Examples of such inter-related systems are a catalytic cracking process and a corresponding catalyst regeneration process, and a carbonaceous fuel oxidation process and a carbonaceous fuel gasification process.

Reference will now be made to the accompanying drawing which illustrate, by way of example, various embodiments of the present invention, and in which:—

Figure 1 is a diagrammatic view of a combination of two fluidised bed disposed within the same containing vessel, one above the other;

Figures 2 and 3 show diagrammatically the combination of Figure 1 wherein the two fluidised beds are spacially separated;

Figure 4 shows diagrammatically a combination of two fluidised beds disposed within the same containing vessel, one being disposed in an annulus around the other; and

Figure 5 is a diagrammatic cross-sectional view of a heat pipe used in the present invention.

The embodiments illustrated in Figures 1 to 4 of the drawings will be described with specific reference to the gasification of carbonaceous fuels to yield a "process" gas. In this context, a "process" gas is a gas such as hydrogen, carbon dioxide, carbon monoxide, nitrogen and methane which can be formed by subjecting a carbonaceous fuel such as coal or lignite to the action of steam with or without air, oxygen, carbon dioxide, carbon monoxide, hydrogen, methane or higher hydrocarbons.

The precise combination of these gases or vapours fed to the process will depend, of course, on the nature of the process gas or gases required. For the production of a process stream which is rich in hydrogen and carbon monoxide, it is often a disadvantage to have nitrogen present because it acts as a diluent. Such a mixture can be produced by excluding air from the feed gas. On the other hand, a gaseous mixture containing nitrogen might well be required for the production of ammonia or another gaseous or vaporous product containing nitrogen. This can be achieved by including air or nitrogen in the gases passed through a reactor containing a carbonaceous material.

Recycling of process gas streams is also well known and is used to perform a variety of functions: to enrich the feed gases with additional components, to assist with the decomposition of the carbonaceous fuel, to remove undesirable products from the process stream by reaction with the carbonaceous fuel, or to improve the over-all materials balance of the process by reacting compnents of the process stream which would otherwise be rejected from the system.

In general when a product stream leaving a gasification process is richer in hydrogen and carbon monoxide than the feed stream entering the process, the over-all reaction is endothermic. These heat requirements are usually met by burning a portion of the carbonaceous fuel with air or oxygen in a combustion apparatus. In the following exemplified systems; this combustion apparatus takes the form of a further gas/solid fluidised bed (hereinafter referred to as the Combustion Bed).

Referring now to the system illustrated in Figure 1, a containing vessel 1 is divided into two compartments by an internal partition 2, each containing particulate solid carbonaceous material. In the upper compartment the carbonaceous material 3 is supported on a grid 4. The grid is so constructed as to

bear the weight of the solid material above it whilst at the same time allowing for the housing of the equipment necessary for distribution of the incoming fluidising stream 12. A similar grid 6 is disposed in the lower compartment to carry the solid carbonaceous material 5 and to the house the gas distribution equipment for the the fluidising stream 7. The upper grid 4 is also designed to allow the heat pipes 10 to extend therethrough and into the solid material 3. At their other ends, the heat pipes 10 extend into the solid material 5 of the lower compartment.

In operation the lower compartment functions as a combustion bed whilst the upper compartment functions as a reaction bed. The gaseous stream 7 entering the combustion bed fluidises the particulate solid material 5. The stream is an air stream which is optionally pre-heated and carries sufficient oxygen for the complete combustion of the solid material 5. The vaporous combustion products stream 8 leaves via the upper part of the compartment, whilst the ash 9 leaves via the lower part of the compartment. A suitable locking apparatus is provided to permit the discharge of the ash whilst preventing the release of uncombusted material or vaporous combustion products.

The heat generated by the combustion process is absorbed by the heat pipes 10 and is conveyed by the pipes to the solid material 3 in the upper compartment. Because of the very good heat transfer properties both of heat pipes and of gas/solid fluidised beds, very efficient heat transference is possible between the beds in the lower and the upper compartments.

In the upper compartment, a gaseous feed 12 optionally pre-heated fluidises the solid material 3 and, after reaction, leaves the compartment as gaseous process stream 14. Fresh carbonaceous material 11 is fed into the compartment, again through a suitable locking apparatus to prevent process gas leaving the compartment. After reaction, the spent carbonaceous material 13 is transferred from the upper compartment to the lower compartment via a flow regulator.

In the alternative embodiments illustrated in Figures 2 and 3, the containing vessel 1 only encloses the reaction bed, the combustion bed being contained in a separate vessel 15. Also the heat pipes 10 need not be straight and need not pass through the grid 4 of the reaction bed. Thus in Figure 3 the heat pipes are shown as passing through the side wall of vessel 1 and as bending through 90° before entering the reaction bed. Generally when passing through the side wall of the vessel, the heat pipes present a greater immersed surface area to the bed. Alternatively the pipes may be bent or flattened at their ends to increase the surface area of pipe immersed in each bed and hence increase the rate of heat transfer.

A further alternative is illustrated in Figure 4. Here the containing vessel 1 is divided into an outer annular compartment and an inner circular compartment, by means of a vertical baffle 2. The baffle 2 is arranged to divide both the space above the fluidised bed and the bed itself into two separate compartments, but it does include a gap at its lower end to allow material to pass from one bed to the other adjacent bed across the combined grid 4. Fresh solid material 11 is supplied to the inner bed 3 and after reaction passes underneath the baffle 2 into the outer bed 5 where it is then combusted. Ash 9 leaves the vessel 1 through its side wall. The grid 4 is a combined unit serving both the combustion air stream 7 and the feed stream 12. These gaseous streams are kept separate through the distribution system and the grid 4, and it has been found that substantially no intermixing of the gaseous streams occurs in the divided vessel 1 beneath the baffle 2, provided that the gap at the bottom of the baffle is kept close to the grid 4. The streamline flow of the gaseous streams appears initially to be undisturbed by the radial movement of the fluidised solid from the inner to the outer bed. Horizontal heat pipes passing through the baffle 2 transfer heat from the outer to the inner bed.

It will be seen in general that the depth of the reaction bed is greater than that of the combustion bed. This is necessary so that the gasification reactions, particularly the carbon monoxide-forming reactions, have sufficient time to take place. Combustion reactions, on the other hand, tend to require only a shallow bed.

A heat pipe suitable for use in the present invention is illustrated in Figure 5 of the drawings. The pipe consists of a high alloy steel tube 20 which is sealed at both ends and contains a small quantity of a working liquid. The liquid is absorbed in a wick 21 arranged as a tubular sleeve lining the inside of the tube 20 and extending the entire length of the tube. The wick 21 usually takes the form of a woven mesh or gauze through which the liquid is able to move by capillary action.

In operation, the heat pipe is disposed with one end in contact with a heat source and the other in contact with a heat sink. As heat is conducted from the heat source through the wall of the pipe and into the wick, liquid is evaporated into the

end space 22 of the tube. Vapour then diffuses through the hollow centre of the tube and condenses onto the wick at the cool end of the tube 23. The liquid then travels along the wick by capillary action to be re-evaporated at the hot end 22. Heat is thus transferred from the heat source to the heat sink by means of the absorption and release of the latent heat of vaporisation of the circulating liquid inside the tube. Heat transfer efficiencies of from 50 to 85% have been achieved for these heat pipes.

The selection of the tube material and the working liquid is generally dependant on the temperature range over which the heat pipe is intended to operate and the environmental conditions to be encountered by the ends of the pipe. In the exemplified embodiments, a temperature range of from 650° to 900°C is utilised with severe conditions of abrasion and corrosion by, for example, sulphur dioxide. Thus a high nickel/chromium alloy steel is used, with molten sodium as the working liquid. Normally, heat pipes are provided with integrally-formed fins or studs in order to improve the rate of heat transference at each end. In certain applications of the present invention, however, abrasion of the external surface of the heat pipes by the fluidised particles in each bed may be such that erosion of these projections would be significant. Heat pipes having relatively smooth external tube walls are therefore desirable.

The number and dimensions of the heat pipes to be used in the exemplified embodiments of the present invention are dependant on the heat transfer duty of the over-all system which is in turn dependant on the capacity of the two compartments, and the composition and flow rates of the product and feed streams. When horizontally disposed, heat pipes function uniformly well; but when vertically disposed or inclined to the vertical, its heat transfer capability is greatly dependant on the respective positions of the heat source and heat sink. It can be seen from Figure 5 that since the condensed liquid moves through the wick by capillary action the level of the condensing end of the pipe should be above the level of the evaporating end of the pipe so that gravity can assist the movement of the liquid. Thus in the illustrated embodiments, the combustion bed is usually placed vertically beneath the reaction bed. Control of the rate of heat transfer can be achieved by careful orientation of the pipes. Lagging of the heat pipes is also important, especially where the heat pipes pass outside the walls of the containing vessels as in the embodiments illustrated in Figures 2 and 3. Control can also be exercised over the rate of heat transfer in these last-mentioned embodiments by adjusting the temperature of the walls of the heat pipes intermediate of the two containing vessels.

In one example of a combined coal gasification/combination process using the present invention, the more important process conditions are as follows:—

A Fuel

Coal

Composition

Dry mineral-free basis

Carbon	92.4	78.4
Hydrogen	4.0	20.4
Nitrogen	1.7	0.6
Sulphur	0.6	0.2
Oxygen	1.3	0.4
	100.0	100.0
	Weight %	Weight %

Nett calorific value 7100 Kcal/Kg

B Operating Conditions in the Reaction Bed

Temperature	800°C
Pressure	4 Bar g.
Coal feed	1100 Kg/h (approximately)
Steam	9800 Kg/h (approximately)
Steam temperature	400°C

C Product Gas Composition

Hydrogen	66.3
Carbon monoxide	8.9
Carbon dioxide	24.4
Nitrogen and Sulphur compounds	0.4
	100.0

Volume % (dry basis)

D Heat Load

Heat transferred from Combustion Bed to Reaction Bed 5.6 million Kcals/h.

E Heat Pipes

Heat transfer coefficient	500 Kcal/h deg C.M^2
Available temperature difference, When the Combustion Bed operates at 900°C	50 deg C
Transfer surface	224 m^2
Heat pipe diameter	80 mm
Number of heat pipes	300
Effective length within the Reaction Bed	3000 mm

F Dimensions of Reaction Bed

Diameter	2200 mm
Free flow area	2.3 m^2
Area occupied by tubes	1.5 m^2
Total area	3.8 m^2
Approximate fluidising velocity based upon inlet steam flow	0.75 m/s

WHAT WE CLAIM IS:—

1. In combination, a gas/solid fluidised bed, a heat sink or heat source, and, as means via which heat is transferred between the heat source or heat sink and the bed, at least one heat pipe partially immersed in the bed.

2. A combination as claimed in claim 1 wherein the heat source or heat sink comprises a second gas/solid fluidised bed in which the heat pipe or pipes is or are partially immersed.

3. A combination as claimed in claim 2 wherein the containing vessel for the first fluidised bed is disposed within the containing vessel for the second fluidised bed.

4. A combination as claimed in claim 2 or claim 3 wherein means are provided for substantially preventing the intermixing of gases flowing to and/or from the first and second fluidised beds.

5. A combination as claimed in any one of claims 2 to 4 wherein means are provided for transferring solid material between the first and second fluidised beds.

6. A conbination as claimed in claim 1 substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

7. A method of operating a gas/solid fluidised bed which comprises passing gas through a solid containing fluidised bed and controlling the temperature of the bed at least in part by means of at least one heat pipe, partially immersed therein, combined with a heat source or heat sink.

8. A method as claimed in claim 7 wherein the heat source or heat sink comprises a second gas/solid fluidised bed in which the heat pipe or pipes is or are partially immersed.

9. A method as claimed in claim 8 wherein the first fluidised bed is performing an endothermic reaction and the second fluidised bed is performing an exothermic reaction.

10. A method as claimed in claim 9 wherein the endothermic reaction comprises the oxidation of a carbonaceous fuel and the exothermic reaction comprises the gasification of a carbonaceous fuel.

11. A method as claimed in claim 9 wherein the endothermic reaction comprises a catalytic cracking process and the exothermic reaction comprises a catalyst regeneration process.

12. A method as claimed in any one of claims 8 to 11 wherein the gases flowing to and/or from the first and second fluidised beds are substantially prevented from intermixing.

13. A method as claimed in any one of claims 8 to 12 wherein solid material is continuously transferred between the first and second fluidised beds.

14. A method as claimed in claim 7 substantially as herebefore described with reference to the accompanying drawings.

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2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG. 1.

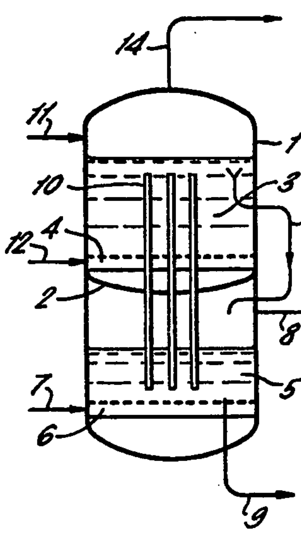

FIG. 2.

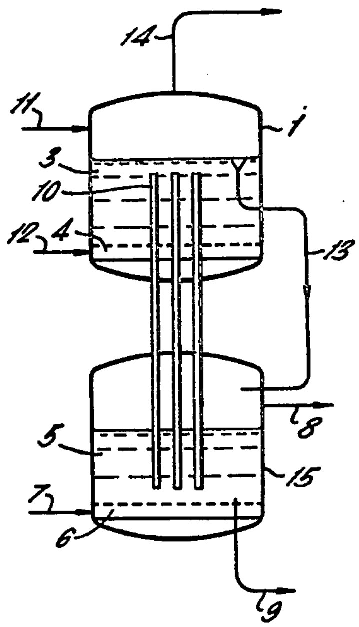

FIG. 3.

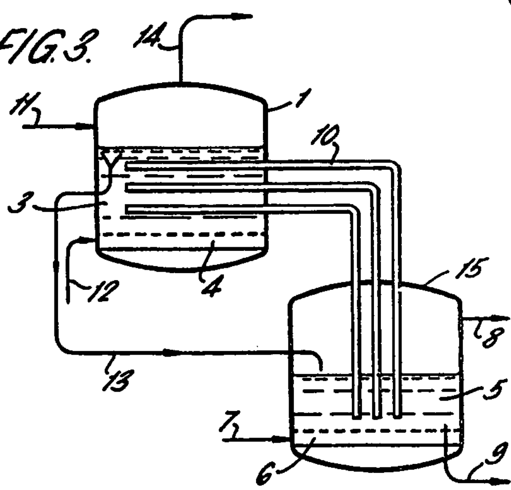

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FIG. 4.

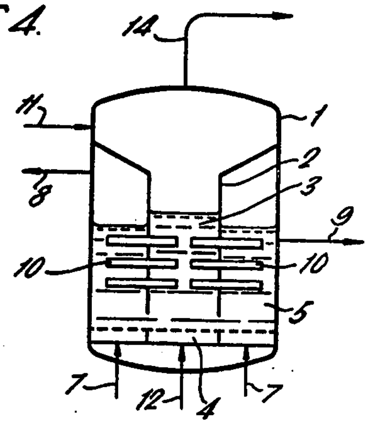

FIG. 5.